After-Initiative Report

Space Object Identification in Living Color (SILC)

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
23-03-2000	Technical Publication Report	22-01-1999 to 29-02-2000

4. TITLE AND SUBTITLE
Space Object Identification in Living Color (SILC)

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
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Irwin Avem Suite 83
Schriever AFB, CO 80912-7383

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
A Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
SILC is a low cost method of multi-color photometry that is utilized to enhance the Space Object Identification (SOI) capability. Currently, USSPACECOM has two radar systems to conduct deep space object identification, which are located in one area of the globe; this limits USSPACECOM global coverage. USSPACECOM also has three Electro-optic ground based deep space surveillance systems that are strategically located around the world. However, they provide only the gross stability of a satellite. This measurement is of limited value to USSPACECOM. The demonstration of SILC shows that GEODSS could use multi color photometry to identify satellites down to their bus class; this is a tremendous leap for SOI capabilities.

15. SUBJECT TERMS
GEODSS, multi-color, photometry, SOI, Space Object Identification

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Vaughn, Roy L., TSgt
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	Same As Report	11	719-564-8968

Executive Overview

During 1999, the Air Force Space Battlelab (SB) partnered with Air Force Research Lab (AFRL) on an initiative called Space Object Identification in Living Color. The purpose of the initiative was to demonstrate to United States Space Command (USSPACECOM) the value of using multi-color photometry to enhance global deep space (A.K.A. geo-synchronous orbit (GEO) space object identification (SOI)) capability.

Currently, USSPACECOM has two types of deep space SOI available, radar and electro-optical (EO). USSPACECOM has two radar systems regularly at hand to conduct deep space SOI, HAYSTACK and MILSTONE. The MILSTONE radar provides strong SOI signature work, while HAYSTACK is able to image deep space satellites. Unfortunately, both of these radar systems are located outside of Westford MA. This limits the global coverage USSPACECOM requires.

On the other hand, USSPACECOM has three Ground-based Electro-Optical Deep Space Surveillance (GEODSS) Systems strategically positioned around the world. However, these primary EO sensors can only provide the gross stability of a satellite. This measurement of satellite stability is of limited value to USSPACECOM.

Due to these constraints, USSPACECOM has been looking for a low-cost method of providing global deep space SOI for its customers. In 1998, The AF Space Battlelab identified a technology called multi-color photometry developed by AFRL as a possible solution to USSPACECOM's challenges.

The demonstration of the technology took 10 months and cost $479,000 total ($279,000 SB and $200,000 AFRL). The results showed that multi-color photometry data collected could be used to identify satellites to their bus class (a leap in deep space SOI capabilities). In addition, the technology could be rapidly incorporated in the GEODSS system for low cost when compared to deploying a global network of radar systems capable of conducting deep space SOI.

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1. Demonstration Mission Statement.

a. Purpose: The purpose of the SILC Demonstration was to prove the Ground-based Electro-optical Deep Space Surveillance (GEODSS) System could use multi-color photometry to meet the Headquarters United States Space Command (HQ USSPACECOM) Combined Intelligence Center (J2FSO) Space Object Identification (SOI) mission.

b. Background:

(1) Early in the space program, USSPACECOM identified SOI as an essential part of the space control mission. To meet this requirement, USSPACECOM used two methods to conduct SOI operations, radar and optical.

(a) USSPACECOM has two radar systems available to conduct deep space SOI; these are the MILSTONE and HAYSTACK radars. Both radar systems are located outside of Westford, Massachusetts. The MILSTONE radar can conduct fine radar signature work that allows confident identification of a satellite, while the HAYSTACK radar can actually image satellites in deep space. Unfortunately, these assets are located in the wrong location for global SOI operations (Lutz.1999).

(b) USSPACECOM has three optical assets called Ground-based Electro-optical Deep Space Surveillance systems located in strategic locations around the world. However, GEODSS, the primary deep space SOI sensors, can not fingerprint or classify objects. This is driven by the GEODSS system's collection method. Currently, the GEODSS telescopes measure the brightness of white light which is plotted against time, providing the gross stability of a space object. In other words, the sensor can only tell if the satellite is stable, rotating, or spinning out of control. This information is of limited value to USSPACECOM's SOI mission (Lutz.1999).

(2) One possible solution to USSPACECOM's problems was first discussed by Dr John Lambert in 1971. His idea was to use multi-color photometry as an innovative method for deep space SOI in his masters thesis. (Lambert 1971). Air Force Research Laboratories and Massachusetts Institute of Technology Lincoln Laboratory (MIT/LL) studied this concept as having potential in improving SOI. However, the end user, HQ USSPACECOM/J2FSO, was never convinced the studies had enough truth data to show multi-color photometry could drastically improve their SOI mission (Lutz.1999).

(3) The Air Force Space Battlelab reviewed several reports to validate that multi-color photometry was an innovative method for meeting USSPACECOM/J2FSO requirements (Lambert. 1971) (Beavers, Cho, Irelan, Trujillo, Olden. 1994) (Beavers W.I., Wacker S.W., Irelan R.L., Taff L.G., Rork E.W., and Iuetter S.I. 1989) (Sovari. 1979). The SB then worked with AFRL,

HQ USSPACECOM/J2FSO, HQ Air Force Space Command (AFSPC)/DOY and AFRL/DE to develop a demonstration that would prove the effectiveness of multi-color photometry.

(4) If this demonstration was successful, HQ USSPACECOM/J2FSO agreed to incorporate multi-color photometry into GEODSS as soon as possible. This would provide them the global SOI capability USSPACECOM requires. (DeLoughry 1998)

c. Objectives: SILC was an approved SB Kenney Class Initiative (KBI) to examine the military utility of using multi-color photometry to identify deep space objects. The initiative used the following objectives.

(1) Demonstrate the capability of multi-spectral or multi-color photometry to identify deep space satellites.

(2) Demonstrate the capability of multi-spectral or multi-color photometry to solve cross tagging situations.

(3) Demonstrate the capability of multi-spectral or multi-color photometry to evaluate the operational status of a deep space satellite.

d. Length of Time:

(1) The original idea was submitted by Capt Allen Schmelzel of Phillips Laboratory on 15 Jul 97, 15 days after the Space Battlelab stood up. Due to a backlog exceeding 300 ideas, the idea was not researched until Dec 97. The Space Battlelab presented the idea to the Battlelab Planning Cell on 25 Jun 98. The Space Battlelab General Officer Advisory Group (GOAG) approved the SILC detailed planning on 8 Jul 98 and approved the demonstration execution on 22 Jan 99 (SB Demonstration Database, 1999).

(2) SILC officially began on 15 Feb 99.

(a) 15 Feb 99 - 22 Sep 99 - Data collection
(b) 27 May 99 - 20 Oct 99 - Data base development
(c) 27 May 99 - 20 Oct 99 - Data interpretation
(d) 15 Jul 99 - 22 Oct 99 - Follow-on filter selection
(e) 24 - 26 Oct 99 Final demonstration of technology capabilities.

e. Budget:

(1) Space Battlelab Provided $279K for the SILC Initiative.

(a) Boeing Support	$200K
(b) Computer software development and analysis	$ 64K

(c) SB Travel Costs	$ 15K
(d) Total Space Battlelab cost:	$279K

(2) In addition, AFRL Directed Energy Directorate, Advanced Optics & Imaging Division's Space Surveillance System (AFRL Detachment 15) provided $200K for the purchase of required equipment (spectrometer, additional filters and camera) mounting costs and cost associated with AFRL Detachment 15 support.

2. Course of Action.

a. Overview:

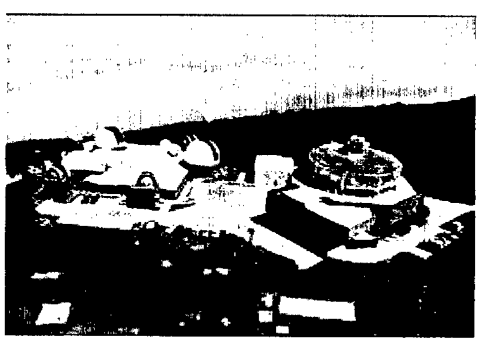
(1) To effectively meet the KBI goals SB partnered with AFRL Detachment 15 and leveraged AFSPC assets at Maui Space Surveillance Complex upon Mt Haleakala to collect 2,300 multi-color photometry observations over a 8-month period. These observations focused on 10 primary satellites.

(2) Once AFRL Detachment 15 conducted data reduction, the data was transmitted to AFRL Directed Energy Directorate's Systems Assessment (AFRL/DEPA) and Surveillance Technologies (AFRL/DEBS) branches at Kirtland AFB NM. There the data was processed by AFRL/DEPA's neural network software and AFRL/DEBS' pattern recognition software to match multi-color photometry signature to each satellite and determine filters for satellite SOI.

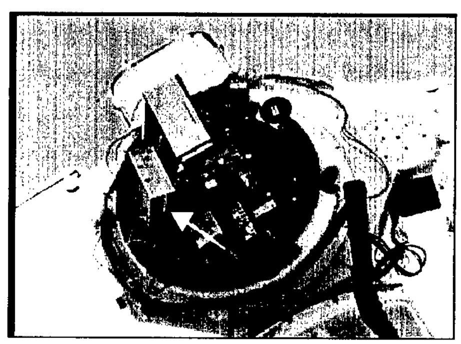
(3) In addition, AFRL/DEBS provided the team the ability to leverage research data collected by the Schafer Corporation and the University of New Mexico's Capella Peak Observatory from closely related programs.

b. System and Demonstration Description

(1) The demonstration collection team used the 1.6 meter telescope at the Maui Space Surveillance Site (MSSS) (see figure 1) for data collection.



Maui Space Surveillance Station
Figure 1



ESSEX Spectrometer
Figure 2

(2) The collection team accessed a spectrometer (see figure 2) originally purchased for the Electric Propulsion Space Experiment (ESSEX) to cut demonstration costs for data collection.

(3) The spectrometry data was reduced to remove atmospheric conditions and to remove stray cosmic radiation (See SILC Final Report, page 15, for more detailed results).

(4) The data was transferred using the AFRL Detachment 15 web site (ulua.mhpcc.af.mil).

(5) The data was then interpreted by AFRL/DEBS to select the best filters to be used in an operational system.

(6) The data was processed by AFRL/DEBS' pattern recognition software, called MAT Lab, by Math Works and AFRL/DEPA's neural network software, called IDL, by Research Incorporated.

(a) AFRL/DEBS simulated the use of color wheel filters by breaking the SILC spectral data into key spectral bandwidths that correspond to the recommended color filters (See SILC Final Report, pages 17 – 53, for more detailed results).

(b) AFRL/DEPA broke the spectral data into equal parts. They then averaged each equal part to be processed. The data was then interpreted by a neural network that compared one satellite class against the other satellite classes (See SILC Final Report, pages 53 – 58, for more detailed results).

c. Targets:

(1) Targets were selected based off two basic issues.

(a) All targets used needed to be collected on satellites visible by both AFRL Detachment 15 at Maui, HI and Capella Peak Observatory, NM.

(b) To ensure that cross-tagged satellites would not corrupt the database, data collection of all satellites were separated from other geo-belt satellites.

(2) See Table 1 for list of the targets observed.

(3) During the final demonstration an eleventh satellite (TDRSS) was added to verify if the multi-color photometry could classify an unknown satellite.

Table 1: Target Satellites used for SILC

SCC#	Name	Bus Type
23467	UFO	Hughes 601
23313	Sol 2	Hughes 601
23175	Pas 2	Hughes 601
21222	Anik E2	GE Satcom 500
22117	Satcom C3	GE Satcom 500
21639	TDRS3	TDRS
25331	Echostar 4	GE 7000
21641	IUS Rocket Body	IUS Upper Stage
24786	GOES 10	Loral

3. Results.

a. Objective One: Demonstrate the capability of multi-spectral or multi-color photometry to identify deep space satellites.

(1) MET: The SILC team was able to demonstrate that multi-color photometry broke down in specific data clusters for each satellite class that could be analyzed by several methods. In addition, the data processing systems used were able to break down the data collection to reliably classify satellite classes. During the final demonstration the SILC team was able to classify satellites by bus structure at an average 86.6% effectiveness rate, using the pattern recognition system, while the neural network software was able to classify the bus structure to a 75% effectiveness rate (See SILC Final Report, pages 49 and 57, for more detailed results).

(2) Note: While USSPACECOM/J2FSO was hoping for an actual fingerprint of specific satellites, they were impressed by the ability of multi-color photometry's ability to classify satellites. This is a drastic improvement over the traditional GEODSS SOI data collection method (Lutz, 1999).

b. Objective Two: Demonstrate the capability of multi-spectral or multi-color photometry to solve cross-tagging situations.

MET: The SILC team simulated a satellite cluster by searching data for observation that was taking within 0.5 degrees of the same solar phase angle. This simulation demonstrated that SILC techniques identified significant differences between these satellites, thus showing that SILC techniques could resolve cross-tagging (See SILC Final Report, page 51, for more detailed results).

c. Objective Three: Demonstrate the capability of multi-spectral or multi-color photometry to evaluate the operational status of a deep space satellite.

There was not enough data to conduct finite comparisons between operational and nonoperational satellites.

d. Additional benefits:

(1) AFRL/DEBS worked with Schafer Corporation and the University of New Mexico's Capilla Peak Observatory to select the most effective filters to use for multi-color photometry (see SILC Final Report, pages 30-41, for specific filter sets).

(2) AFRL Det 15's high quality spectral observations were collected into a well organized data base managed by AFRL/DEBS.

4. Estimated Transition Costs

a. Due to proactive work by HQ AFSPC/DR in the retention of color wheel technologies into the DEEP STARE sustainment upgrade, the total cost for implementing SILC technologies should be marginal.

(1) A set of color filters per EO location ($2,000).

(2) The cost of integrating SILC into GEODSS and other electro-optical sensors software and communication systems. This cost can not be estimated at this time due to source selection on the DEEP STARE sustainment upgrade. However, this should be a relatively low cost item. Again HQ AFSPC/DR was very proactive in ensuring this requirement was addressed in the DEEP STARE sustainment upgrade migration plan allowing relatively rapid transition of the technology (Nutter, 2000).

(3) The integration of a pattern recognition software system into USSPACECOM/J2FSO. USSPACECOM/J2FSO currently has planned out a budget to upgrade their SOI software development (around $1 million per year). If USSPACECOM/J2FSO uses these funds, they should be able to modify their pattern recognition tool, the Lincoln Photometric System (LPS). SILC technologies could be integrated into LPS for about $80K per year over two years ($160K total). (Lutz, 1999).

(4) The training of personnel.

5. Recommendations.

a. HQ AFSPC/DOY and DRC work with ESC to Incorporate SILC-based technology into GEODSS and other ground-based and space-based electro-optical SOI systems as soon as possible.

b. HQ USSPACECOM/J2FSO invest funds to develop and purchase a user-friendly processing program to interpret multi-color photometry data.

(1) The best path would be for HQ USSPACECOM/J2FSO to work with AFRL/DE and MIT/LL to incorporate SILC technologies into a software upgrade of the LPS.

(2) HQ USSPACECOM/J2FSO should start building a data base on SILC-related signatures.

c. AFRL conduct further research on application of SILC-related technologies to meet more challenging needs of status and characterization of satellites.

6. CONCLUSION

The Space Battlelab SILC demonstration was successful in showing that multi-color photometry could improve USSPACECOM's global SOI capability. Furthermore, this technology could be implemented rapidly and at a relatively low cost.

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